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RESEARCH ARTICLE

$SPEI_{PM}$-based research on drought impact on maize yield in North China Plain

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Abstract

The calculation method of potential evapotranspiration (PET) was improved by adopting a more reliable PET estimate based on the Penman-Monteith equation into the standardized precipitation evapotranspiration index (SPEI) in this study ($SPEI_{PM}$). This improvement increased the applicability of SPEI in North China Plain (NCP). The historic meteorological data during 1962–2011 were used to calculate $SPEI_{PM}$. The detrended yields of maize from Hebei, Henan, Shandong, Beijing, and Tianjin provinces/cities of NCP were obtained by linear sliding average method. Then regression analysis was made to study the relationships between detrended yields and SPEI values. Different time scales were applied, and thus $SPEI_{PM}$ was mentioned as $SPEI_{PMk}$-j (k=time scale, 1, 2, 3, 4,…, 24 mon; j=month, 1, 2, 3,..., 12), among which $SPEI_{PM3}$-8 reflected the water condition from June to August, a period of heavy precipitation and vigorous growth of maize in NCP. $SPEI_{PM3}$-8 was highly correlated with detrended yield in this region, which can effectively evaluate the effect of drought on maize yield. Additionally, this relationship becomes more significant in recent 20 yr. The regression model based on the SPEI series explained 64.8% of the variability of the annual detrended yield in Beijing, 45.2% in Henan, 58.6% in Shandong, and 54.6% in Hebei. Moreover, when $SPEI_{PM3}$-8 is in the range of –0.6 to 1.1, –0.9 to 0.8 and –0.8 to 2.3, the detrended yield increases in Shandong, Henan and Beijing. The yield increasing range was during normal water condition in Shandong and Henan, where precipitation was abundant. It indicated that the field management matched well with local water condition and thus allowed stable and high yield. Maize yield increase in these two provinces in the future can be realized by further improving water use efficiency and enhancing the stress resistance as well as yield stability. In Hebei and Beijing, the precipitation is less and thus the normal water condition cannot meet the high yield target. Increasing of water input and improving water use efficiency are both strategies for future yield increase. As global climate change became stronger and yield demands increased, the relationship between drought and maize yield became much closer in NCP too. The research of drought monitoring method and strategies for yield increase should be enhanced in the future, so as to provide strong supports for food security and agricultural sustainable development in China.

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1. Introduction

North China Plain (NCP), is known to be one of China's most important agricultural regions, covering about 18 million ha of farm land and producing about 21.6% of the total grain yield in China. Winter wheat and summer maize rotation system is the major planting pattern in this region. However, it becomes more difficult to maintain and achieve further productivity increases of NCP due to severe drought risk. Past and present climate trends and variability in NCP can be characterized as an increase of air temperatures and a decrease of precipitation. In addition, the intensity and frequency of drought events increased over the last decades (Dai 2011; Tao *et al*. 2012; Li and Geng 2013; Wang *et al*. 2014). Drought is one of the most complex climatic phenomena affecting agricultural production. This complexity is related to the difficulty of quantifying drought severity since so many factors can impact the response of crop to drought stress. Up to now, no physical variable is available to quantify drought's intensity, magnitude, duration and spatial extent. Therefore, many studies have been developed for an objective and quantitative evaluation of drought severity. The quantification of drought impacts is commonly done by using the so-called drought indices (Hayes 2000), which are proxies based on climatic information and assumed to adequately quantify the degree of drought hazard. The Palmer drought severity index (PDSI; Palmer 1965), based on a soil water balance equation, and the standardized precipitation index (SPI; McKee *et al*. 1993), based on a precipitation probabilistic approach, are the most advanced drought indices. Recently, a new drought index, the standardized precipitation evapotranspiration index (SPEI; Vicente-Serrano *et al*. 2010) was developed, which was based on a monthly climatic water balance (precipitation minus PET). The SPEI combined the sensitivity of PDSI to changes in evaporation demand, caused by temperature fluctuations and trends, with the simplicity of calculation and the multitemporal nature of the SPI (Potop *et al*. 2012; Vicente-Serrano *et al*. 2012). Over other widely used drought indices, the SPEI's main advantage lies in its ability to identify the role of evapotranspiration and temperature variability with regard to drought assessments in the context of global warming. Most studies have been conducted using SPEI to analyze and monitor drought characteristics, variability and trend in China (Li *et al*. 2012; Shi *et al*. 2012; Su and Li 2012).

In this study, we improved the computation method of SPEI by adopting a more reliable PET estimate based on the Penman-Monteith equation (Allen *et al*. 1998), which could better reflect the role played by PET on drought severity and make the SPEI even more suitable to identify drought-related impacts in our research region. Furthermore, we applied the modified multi-scalar SPEI ($SPEI_{PM}$) drought index to determine the influences of increasing drought on maize yields during the last five decades in the NCP. According to this research, $SPEI_{PM}$ would contribute to policy-making and quick-response to drought stress in crop production and thus achieve stable and high yield.

2. Results

2.1. Temporal evolution of maize yield

To eliminate non-climatic effects on yields, the detrended yield was obtained by subtracting trend yield from the actual yield (Lobell and Asner 2003). This 21-yr linear sliding average method was applied to remove trends in yields (Xue *et al*. 2003). Fig. 1 shows the temporal evolution of maize yield in Hebei, Henan, Shandong, Beijing and Tianjin provinces (cities), China. The ranges of detrended yields are –594.2–729.4 kg ha^{-1} in Hebei, –1 806.0 to 575.5 kg ha^{-1} in Henan, –1 288.2 to 606.8 kg ha^{-1} in Shandong, –1 290.4 to 1 309.9 kg ha^{-1} in Beijing and –1 652.0 to 828.9 kg ha^{-1} in Tianjin, respectively. Correlation analyses between detrended yields and drought disaster area data were made (Table 1). There are highly significant correlations ($P<0.01$) between detrended yields and areas failure harvest caused by drought disasters in Hebei, Henan, Shandong and Tianjin. In Hebei and Tianjin, there are highly significant correlations between detrended yields and areas suffered/affected by drought disasters. The correlations between detrended yields and areas suffered/affected in Shandong are in significant level ($P>0.05$). These results indicate that detrended yields estimated in this research reflected the real situation in history and could be used to study the relationships between yield variations and climate elements.

2.2. The relationship between $SPEI_{PM}$ and maize detrended yield

According to the planting pattern of maize in NCP, 1, 2, 3, and 4 mon time scale SPEIPM were used to identify drought-related impacts during summer maize growing season (June to September). The regression analyses between $SPEI_{PM}$'s and detrended yields were made (data not shown). The results showed that the regression equation